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Kosmahl

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[54] LINEARIZED TRAVELING WAVE AMPLIFIER WITH HARD LIMITER CHARACTERISTICS

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[73] Assignee: The United States of America as respresented by the Administrator of the National Aeronautics and Space Administration, Washington, D.C.

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[22] Filed: Mar. 20, 1985

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 492,522, May 9, 1983, abandoned.

[51] Int. Cl.[4] H01J 25/34
[52] U.S. Cl. 315/3.6; 315/3.5; 315/39.3; 330/43
[58] Field of Search 315/3.5, 3.6, 39.3; 330/43

[56] References Cited

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3,614,517	10/1971	Dionne	315/3.6
3,678,326	7/1982	Heynisch	315/3.6
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3,809,949	5/1974	Scott	315/3.5
3,846,664	11/1974	King et al.	315/3.6
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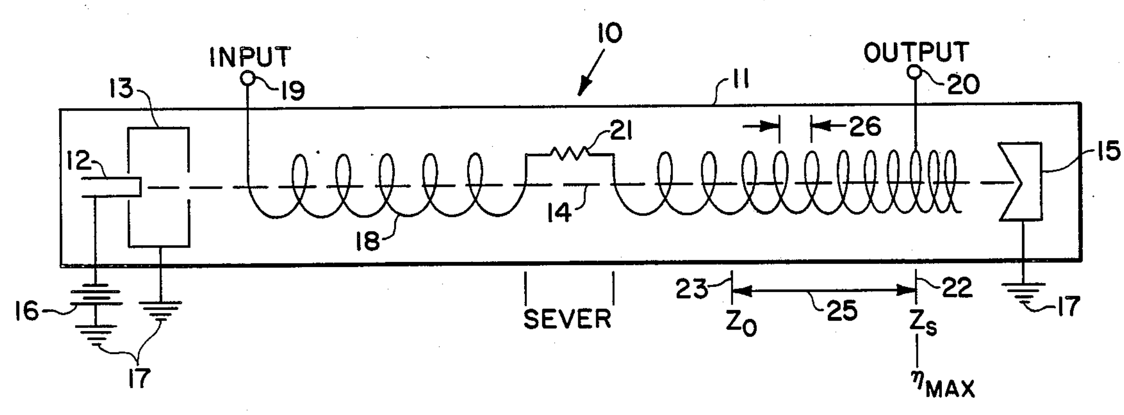
Primary Examiner—Saxfield Chatmon
Attorney, Agent, or Firm—James A. Mackin; John R. Manning

[57] ABSTRACT

The object of the invention is to provide a traveling wave tube with increased linearity to avoid intermodulation of signals being amplified. In a traveling wave tube **10**, as shown in FIG. **1**, the slow wave structure is a helix (**18**) including a sever (**21**). A dynamic velocity taper is provided by gradually reducing the spacing (**26**) between the repeating elements of the slow wave structure which are the windings of helix (**18**). The reduction takes place between Zo indicated by line **23** and Z_s which coincides with the output point of helix (**18**) as indicated by the line (**22**). The spacing (**26**) begins to decrease at Z_o and is decreased by up to about 5% at Z_s. The spacing (**26**) between the repeating elements of the slow wave structure is ideally at an exponential rate because the curve (**27**), as shown in FIG. **3**, increases from Z_o to Zs the point of maximum efficiency and power, at an exponential rate. FIG. **3** shows a coupled cavity traveling wave tube having cavities **32** through **37**. The axial length of cavities (**35**) through (**37**) is gradually reduced between Z_o to Z_s. To this end, the spacing between apertured discs **38** is gradually reduced between Z_o and Z_s from 0.1% to 5% at an exponential rate. In FIG. **4**, curve **28** represents output power (or efficiency) versus input power for a commercial tube. Curve **31** represents the same parameters for a tube embodying the invention and shows the great linearity achieved by the dynamic velocity taper.

7 Claims, 5 Drawing Figures



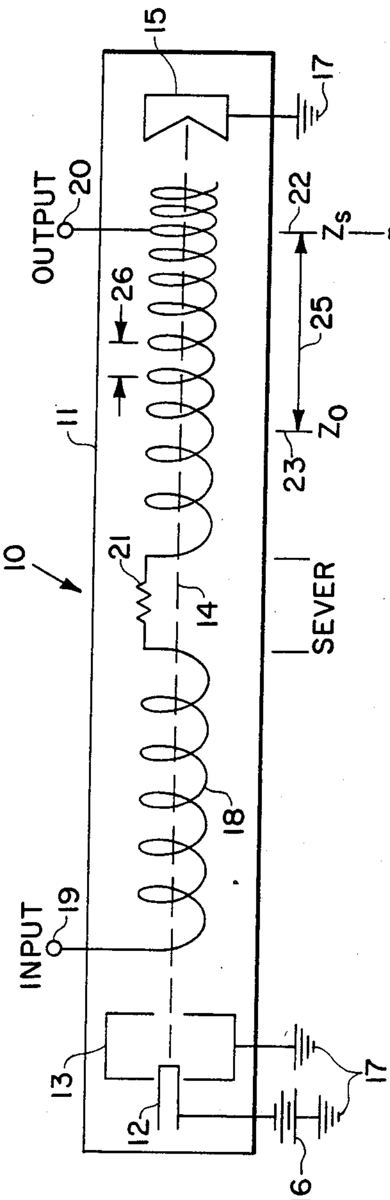

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FIG. 1

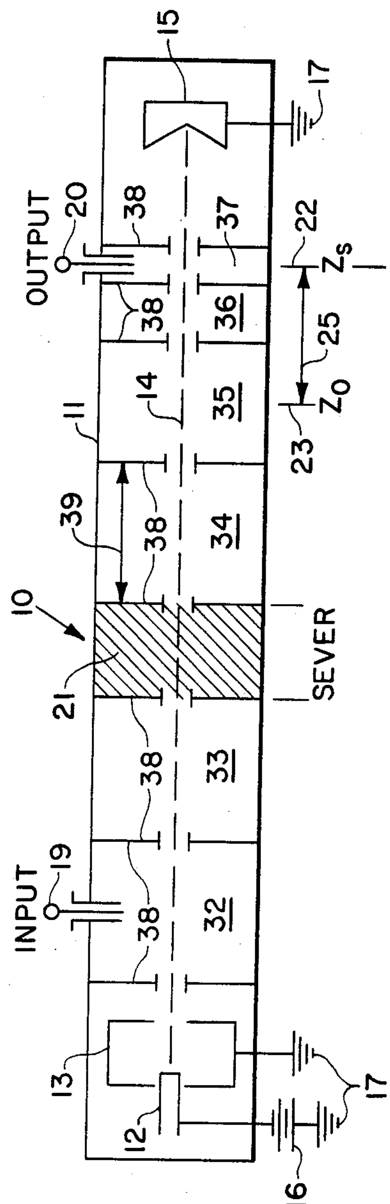
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FIG. 2

EFFICIENCY VS. SWS LENGTH (RELATIVE)

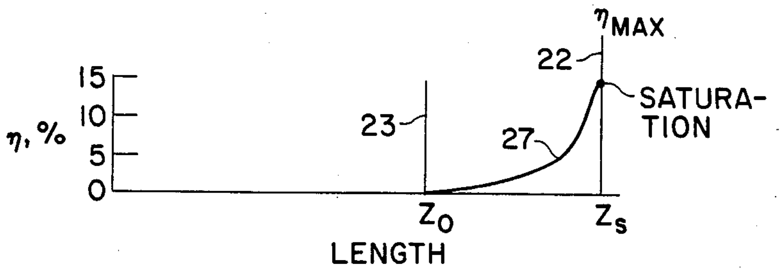


FIG. 3

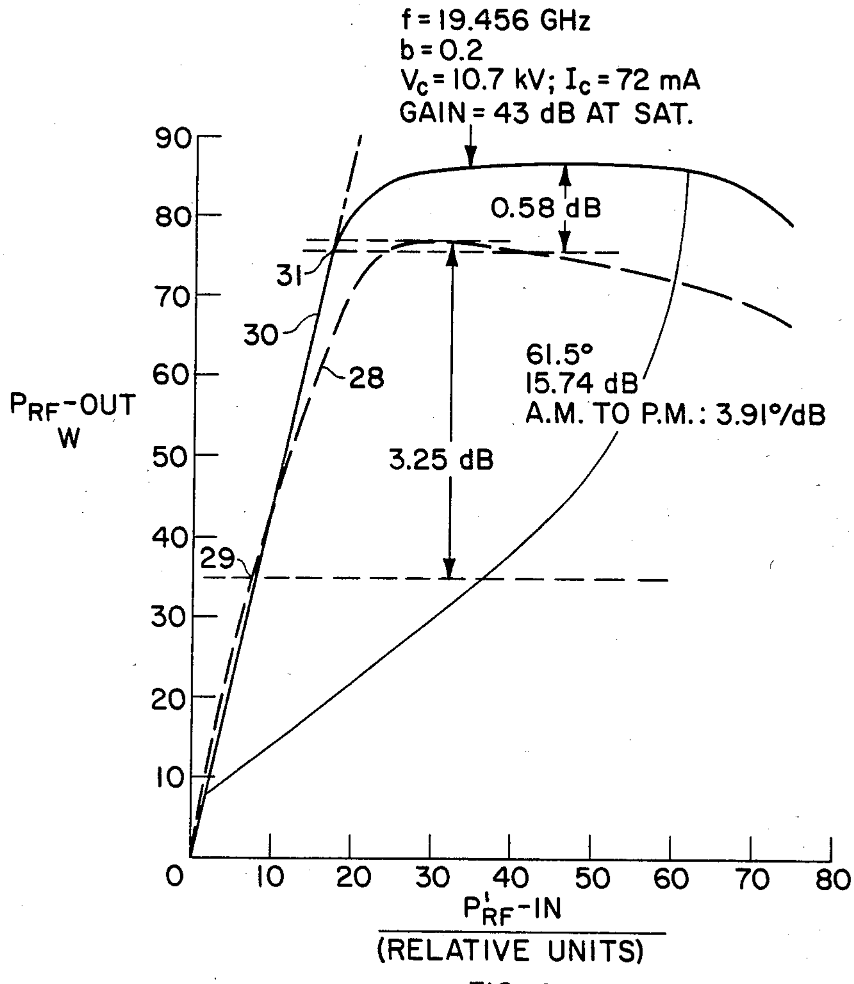
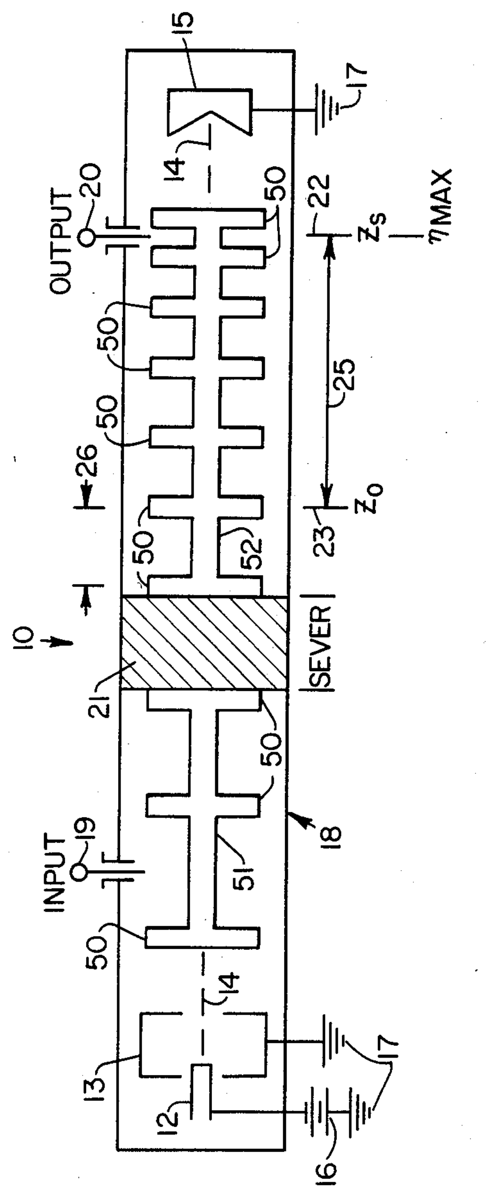


FIG. 4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Z_S
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FIG. 5

LINEARIZED TRAVELING WAVE AMPLIFIER WITH HARD LIMITER CHARACTERISTICS

ORIGIN OF THE INVENTION

This invention was made by an employee of the United States Government and may be manufactured or used by or for governmental purposes without the payment of any royalties thereon or therefor.

This application is a continuation of application Ser. No. 492,522 filed May 9, 1983, abandoned.

TECHNICAL FIELD

This invention relates to radiofrequency amplifying tubes and, more particularly, to traveling wave amplifying tubes wherein a traveling electromagnetic wave and an electron beam interact to effect amplification of a radiofrequency signal.

Because of the presently increasing demand for satellite-to-earth communications, it is clear that the capacity limits of the frequency bands of presently-used satellites will be exceeded within a few years. Thus, it is desirable to be able to transmit many different signals by various techniques such as frequency modulation or pulse width modulation either of which may be multiplexed.

To avoid intermodulation between the signals in a traveling wave amplifier tube, it is essential that the tube be operated only in its linear region. Consequently, it has been necessary to operate traveling wave tubes under a back-off condition wherein the output power with relation to the input power is much less than maximum in order to stay in a linear region of operation. Accordingly, it would be advantageous to have a traveling wave tube which has a greatly increased range of linear operation.

PRIOR ART

U.S. Pat. No. 3,668,544 to Lien discloses a slow wave tube wherein the signal to be amplified and a harmonic thereof are applied concurrently over at least a portion of the slow wave circuit to increase the RF conversion efficiency of the tube.

U.S. Pat. No. 3,614,517 to Dionne introduces an intermediate phase velocity profile at a relatively low level of electron beam energy extraction and well before tube saturation to increase efficiency of the tube.

U.S. Pat. No. 3,809,949 to Scott discloses a vane loaded helix derived slow wave circuit wherein the degree of penetration of the vanes into the slow wave circuit is increased at the output end of the tube for introducing a frequency dependent velocity taper to increase efficiency of the tube.

U.S. Pat. No. 3,940,654 to Winslow employs a helical structure that is loaded by placing longitudinal vanes or conductors around the helix adjacent its output end. The conductors are arranged such that the spacing from the conductor to the slow wave circuit decreases in a direction toward the collector. The Winslow structure increases the efficiency and the band width of a traveling wave tube but does not improve linearity.

U.S. Pat. No. 3,903,449 to Scott anisotropically loads the helix of a traveling wave tube with vanes or sectors comprised of berrylia or boron nitride rods. These loading elements increase the operating band width over which the relatively high gain and efficiency are obtainable.

U.S. Pat. No. 4,107,527 to Yuasa et al discloses a traveling wave tube having a slow wave circuit consisting of a constant phase velocity section and a phase velocity tapering section serially arranged between an attenuator and the output of the slow wave circuit. A particular ratio between the length of the constant phase velocity section and the phase velocity tapering section is prescribed for the purpose of improving the tube efficiency.

U.S. Pat. No. 3,972,005 to Nevins, Jr. et al discloses a traveling wave tube having a conductive circuit loading structure surrounding a helix slow wave circuit and extending for at least half the length of the helix and preferably for its entire length. The conductive circuit loading structure comprises a plurality of conductors disposed around the helix and arranged to conduct current associated with the radial frequency fields substantially only in the radial or axial direction of the helix and not in the circumferential direction. Such an arrangement results in an ultra wide band, high efficiency traveling wave tube.

U.S. Pat. No. 3,758,811 to Wong is concerned with the reduction of intermodulation products, which reduction may be achieved by increased linearity of operation of a traveling wave tube. The slow wave structure of Wong's traveling wave tube comprises a helix divided into three sections. The first section is a slow velocity and attenuator circuit; the second section is a positive velocity step producer and the third section is a fast velocity circuit section having less pitch than the first section. Wong applies a positive velocity taper abruptly to the traveling wave.

DISCLOSURE OF THE INVENTION

In accordance with the present invention, a dynamic velocity taper is provided for a traveling wave tube. The taper begins at a point on the tube slow wave structure at which efficiency begins to become greater than about 0.1% and extends in a downstream direction toward a collector electrode to the point at which the output signal is picked off the slow wave circuit.

The dynamic velocity taper is achieved by gradually reducing the spacing between repeating elements of the slow wave structure over a prescribed distance. The reduction in spacing between the slow wave structure repeating elements starts at about 0.1% efficiency and increases to about 15% efficiency. Preferably, the reduction in spacing is at an exponential rate.

The dynamic velocity taper maintains an optimum phase relationship between the traveling wave of the slow wave structure and bunches of electrons in the electron beam. Since a computed reduction in energy of the electron bunches is used to determine the phase velocity of the slow wave circuit, it is then dynamically matched to the rate of loss of energy. The desired dynamic velocity taper may be precomputed and a slow wave structure designed accordingly, following the computer outputs.

The use of the dynamic velocity taper in accordance with the present invention provides for a traveling wave tube a characteristic that approaches that of an ideal hard limiter. Thus, the linearity of a traveling wave tube is greatly increased and the efficiency is also increased by a factor of about 1.1 to 1.5.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal schematic view of a traveling wave tube (TWT) having a helical coil, slow wave structure (SWS) embodying the invention.

FIG. 2 is a longitudinal schematic view of a coupled cavity TWT embodying the invention.

FIG. 3 is a graph showing the efficiency increase along the SWS to the point of saturation.

FIG. 4 is a graph of output power versus input power for a commercial TWT and for one utilizing the invention.

FIG. 5 is a longitudinal schematic view of a TWT wherein the SWS embodying the invention is a ring-bar circuit.

MODE FOR CARRYING OUT THE INVENTION

Referring to FIG. 1, there is shown a traveling wave tube **10** comprised of an envelope **11** with an electron emitting cathode **12** and an accelerating anode **13** at one end. Electrons emitted by cathode **12** are accelerated by the anode **13** are formed into a beam **14** which is collected at the other end of envelope **11** by a collector **15**. The beam **14** is prevented from expanding due to a magnetic field from a solenoid (not shown) or permanent magnets coaxial with the envelope **11** as is common practice with traveling wave tubes having a helical slow wave structure (SWS).

Cathode **12** is maintained at a negative potential with respect to the anode **13** and the collector **15** by means of a DC source **16**, the negative side of which is connected to the cathode **12**, the positive side being connected to ground as at **17**. The anode **13** and the collector **15** are grounded as at **17** and, accordingly, are positive with respect to cathode **12**. A heater (not shown) is normally provided for cathode **12** to cause electron emission.

The slow wave structure of TWT **10** comprises a helix **18** in which the turns may be considered as repeating structural elements. A signal input terminal **19** is connected to the end of the helix closest to the cathode **12** at one end of envelope **11** while an output terminal **20** is connected to the helix **18** either at its end or at a point slightly upstream of its end which is adjacent collector **15**. One or more severs **21** may be provided for the helix in a manner well-known in the prior art.

Important reference points on the helix **18** are identified by the line **23** representing the point Z_o at which efficiency of the TWT **10** is approximately 0.1% and line **22** representing the point Z_s at which the output signal is taken off by output terminal **20**. The double ended arrow **25** indicates the axial distance between Z_o and Z_s over which axial spacing **26** between structural elements such as the windings of helix **18** is reduced.

In FIG. 3, the curve **27** is a graph of efficiency vs. slow wave structure length. The vertical lines **22** and **23** represent the same slow wave structure axial points which they delineate in FIG. 1. As shown by the curve **27**, efficiency increases exponentially from about 0.1% at Z_o to about 15% at Z_s which represents the output point of the helix **18** in FIG. 1. Vertical line **22** corresponds to the output point of the helix which is the point of maximum efficiency at which saturation occurs.

Referring now to FIG. 4, there is shown a curve **28** which is a graph of TWT output power or efficiency vs. input power. As discussed previously, in order to avoid intermodulation where a plurality of RF signals are being amplified, a traveling wave amplifier tube must be operated only in its linear region. The curve **28** is linear only up to approximately point **29**. Thus, operation of the tube would have to be backed off to point **29**, greatly reducing output efficiency and power.

Curve **30** is a graph of output efficiency or output power vs. power input for a traveling wave tube embodying the invention. This curve is linear up to approximately the point **31** and closely approximates the curve of a hard limiter. Accordingly, a TWT embodying the invention has very high linearity and higher efficiency for certain rates of reduction of repeating element spacing.

In FIG. 2, there is shown a coupled cavity traveling wave tube **10** wherein components corresponding to those shown in FIG. 1 are identified by the same numerals. Such components include the envelope **11**, cathode **12**, anode **13**, electron beam **14**, collector **15**, DC source **16** and the common grounds **17**. Additional parts of the TWT of FIG. 2 corresponding to parts in FIG. 1 include input terminal **19**, output terminal **20** and a sever **21**.

In the tube of FIG. 2, cavities **32** through **37** are formed by a plurality of axially spaced discs **38**. The discs **38** have central apertures to allow for passage of the electron beam **14** and are perpendicular to the long axis of the envelope **11**.

It will be seen that the axial length of cavity **37** is smaller than that of **36** which, in turn, is smaller than that of **35**, with **35** having a smaller axial length than cavity **34**. Cavities **32**, **33** and **34** all have the same axial length which is determined by the spacing between the discs **38** as indicated by the double ended arrow **39**.

In a downstream direction, that is, going toward collector **15**, the axial spacing of discs **38** decreases after point Z_o to form the cavities **35–37**. As in the case of the TWT shown in FIG. 1, the spacing between the discs **38**, the repeating elements, is greatly exaggerated for purposes of illustration. In an actual coupled cavity tube, there would be many more cavities and the reduction in spacing between the repeating elements **38** would be much less drastic and would be at a gradual rate of reduction between 0.1% efficiency and 15% efficiency between Z_o and Z_s, the decrease being preferably at an exponential rate to obtain maximum linearity.

In FIG. 5 there is shown a TWT **10** having a ring bar type SWS. The same numerals are used to identify corresponding parts and items in FIGS. 1 and 5 and include envelope **11**, cathode **12**, anode **13**, electron beam **14**, collector **15**, DC source **16**, grounds **17**, terminals **19**,**20** and sever **21**. The ring bar SWS is comprised of rings **50** the rings being connected by bars **51** upstream of sever **21** and by bars **52** downstream of sever **21**. From the point Z_o on the SWS indicated by line **23** to the point Z_s indicated by line **22** the spacing between rings **50** gradually decreases in a downstream direction preferrably at an exponential rate.

The equations below establish the parameters for the determination of dynamic velocity taper.

$$b(Z)=b_o[1+\alpha\eta(Z)] \quad (1)$$

$$\eta(Z)=e^{\Gamma(Z-Z_o)}-1. \quad (2)$$

$$b_o=\frac{u-V_p}{C\,V_p} \quad (3)$$

$$b(Z)=\frac{u-V_p(Z)}{C\,V_p(Z)} \quad (4)$$

-continued

$$V_p(Z) = \frac{u}{1 + Cb(Z)} \quad (5)$$

α=constant to be determined, $0<\alpha<50$
b_o=Pierce's velocity parameter (constant)
$b(Z)$=modified, dynamic velocity parameter
C=Pierce's gain (efficiency parameter)
u=dc electron velocity in the TWT
V_p=initial, constant phase velocity of the slow wave circuit
$V_p(Z)$=modified, dynamic phase velocity of the slow wave circuit.

In the physical implementation of the invention, the dynamic velocity taper should be placed downstream of the last sever, where the local efficiency on the circuit $\eta(Z)$ just begins to become larger than zero, $\eta(Z) \geqq 0.1\% \geqq 0.001$. In this region which begins at $Z=Z_o$ and ends at $Z=Z_s$ (saturation) the efficiency $\eta(Z)$ is approximated by the expression (2) above

It may be seen that since

$\eta(Z_o)=0$ and because $\eta(Z_s)=\eta_s$ is the efficiency at saturation of a conventional, untapered TWT, the determination of Γ may be made.

Thus, since

$$e^{\Gamma(Z_s-Z_o)}-1=\eta_s,$$

$$e^{\Gamma(Z_s-Z_o)}=1+\eta_s$$

and

$$\Gamma(Z_s-Z_o)=\ln(1+\eta_s)$$

which yields

$$\Gamma = \frac{\ln(1+\eta_s)}{Z_s - Z_o} \approx \frac{\eta}{Z_s - Z_o}$$

Thus, all the parameters for the determination of the dynamic velocity taper are known from equations (4) and (5). The choice of the parameter α is made such as to produce the highest degree of linearity with an acceptable degree of AM to PM conversion, e.g.: less than 5° per decibel. Note that the velocity taper must not be placed in the small signal region.

As discussed above, the efficiency of a TWT embodying the instant invention increases from about 0.1% at Z_o on the SWS to about 15% at Z_s. The spacing between all repeating elements of the SWS, i.e. the coils of helix **18** in FIG. **1**, the walls **38** of FIG. **2** and the rings **50** of FIG. **5**, is constant from the sever **21** to Z_o. Therefore the reduction in spacing is zero for that portion of the SWS upstream of sever **21**.

The reduction in spacing begins at point Z_o and increases to between 5% and 15% at Z_s with 5% providing greatest linearity and 15% providing most efficiency. Thus, the spacing between repeating elements of the SWS is reduced in a downstream direction from 0% at Z_o to where the efficiency is about 0.1% to between 5% and 15% at Z_s where the efficiency is about 15%.

While the invention has been described with respect to amplifying tubes embodying coupled cavities or helixes, it is applicable as well to other traveling wave tubes having slow wave structures comprised of repeating elements. Such tubes include those with ladder or ring-bar circuits for example.

It will be understood that changes and modifications may be made to the above described invention without departing from its spirit and scope as set forth in the claims appended hereto.

I claim:

1. In a traveling wave tube (TWT) having a long axis, an output point Zs, an input point, a slow wave structure (SWS), comprised of repeating structural elements disposed along said long axis at least from said input to said output and including at least one sever between said input and said output, the improvement comprising a gradual reduction of the axial spacing of said repeating structural elements at an exponential rate from a point Z_o on the SWS at which efficiency is about 0.1% to said output point Z_s whereby the linearity and efficiency of the TWT are greatly increased by the dynamic velocity taper resulting from the gradual decrease of axial spacing of said repeating structural elements.

2. The TWT of claim **1** wherein the velocity taper increases from 0 to between 5% and 15% from Z_o to Z_s on the SWS.

3. The TWT of claim **1** wherein the SWS is a helix.

4. The TWT of claim **3** wherein a reduction of pitch of the helix increases from 0 to between 5.0% and 15% from Z_o to Z_s on the SWS.

5. The TWT of claim **1** wherein the slow wave structure is a ring bar structure and wherein the spacing between the rings is gradually reduced between Z_o and Z_s such that there is a velocity taper of from 0 to between about 5.0% and 15% between Z_s and Z_o on the SWS.

6. The TWT of claim **1** comprised of coupled cavities formed by apertured discs disposed in said TWT perpendicular to its long axis and wherein the axial spacing between the discs is gradually reduced between the Z_o and Z_s points of the TWT.

7. The TWT of claim **6** wherein the reduction of the spacing is increased from about 0 to between between about 5.0% and 15% between Z_o and Z_s on the SWS.

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